This white paper is the fourth in a five-part series dedicated to examining problems organizations encounter when operating in multimodel environments and the current process improvement approaches such organizations need to consider.

Process Architecture
in a
Multimodel Environment

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March 2008

Software Engineering Institute | **Carnegie Mellon**

Report Documentation Page

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1. REPORT DATE **MAR 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**
4. TITLE AND SUBTITLE **Process Architecture in a Multimodel Environment**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Carnegie Mellon University ,Software Engineering Institute (SEI),Pittsburgh,PA,15213**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**14**	

Acknowledgments

About this series

This white paper is the fourth in a five-part series dedicated to examining problems organizations encounter when operating in multimodel environments and the current process improvement approaches such organizations need to consider. It examines the current state of the practice for defining process architecture in a multimodel environment, methods and techniques used for architecture development, and underlying questions for a research agenda that examines the relationship of technology strategy and composition to process architecture as well as the interoperability and architectural features of different process technologies.

The rest of this series addresses, in more detail, each phase of the reasoning framework for technology harmonization in a multimodel environment:

- The 1st white paper addresses the benefits of a harmonized approach when implementing more than one improvement model, standard, or other technology and provides a high-level description and underlying paradigms of a reasoning framework for technology harmonization.

- The 2nd white paper examines the approaches needed in technology selection including a strategic taxonomy, the decision authorities associated with that selection at all levels in the organization, and considerations for thoughtful sequencing of implementation in alignment with the organization's mission, goals, and objectives.

- The 3rd white paper examines technology composition in relation to the concepts introduced in the previous white papers: a proposed element classification taxonomy to make technology integration effective in practice; and the role of technology structures, granularity and mappings in technology composition.

- The 5th white paper addresses the implementation challenges faced by process improvement professionals in multimodel environments, where it becomes necessary to coordinate roles and responsibilities of the champions for different technologies, to integrate and coordinate training, to optimize audits and appraisals, and develop an integrated approach to project portfolio management.
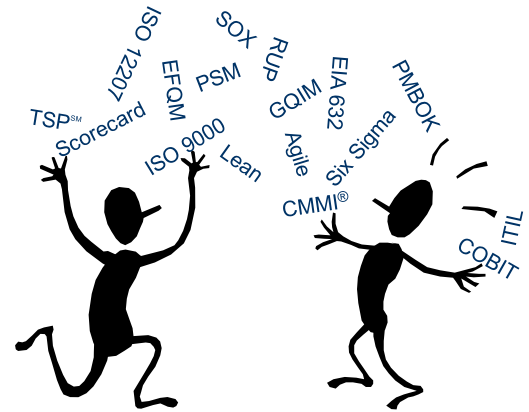
Our approach to multimodel harmonization contains several areas of consideration:

- Alignment of organizational and improvement objectives, including identification of candidate improvement technologies[1]
- Strategic categorization of improvement technologies
- Design of improvement solutions, including
    - Technology composition using element classification and other tactical technology connections
    - Process architecture
- Implementation (or execution) of multimodel process improvement solutions, including measurement of results

Among these areas, process architecture is perhaps the most crucial in our research—it is the underpinning of executed processes, the means by which products are delivered; however its underlying methodologies are still emerging and maturing. While preliminary work has been conducted to address the strategic selection and composition of multiple models, the current understanding of technology interoperability and architectural characteristics is insufficient to inform effective process composition and architecture. Furthermore, there is not a widely held definition of process architecture. Nor is there a common methodological approach that captures all of the needed process features at an architectural (rather than descriptive or procedural) level.

Exacerbating this challenge, globalization, business acquisition, network-centric operations, and other aspects of increasingly complex systems being built across the supply chain—as well as the routine emergence of new process technologies, tools, and regulations—require increasingly agile and robust process composition. Such composition will benefit from the existence of an explicit process architecture and design as well as from a clear relationship to model composition and compliance requirements; however, there is currently no common definition or recommended approach.

Yet, numerous organizations have sufficiently adapted available diagramming techniques to serve their own purposes—however, these are "state of the art" approaches to process architecture, not "state of the practice." Likewise, some organizations have successfully created their own strategic selections and compositions of models and standards, and then look to these same technologies to serve as building blocks from which to create their process definitions. In today's multimodel environment, this is a complex undertaking, where processes must be composed to incorporate features needed for both compliance and mission success. We have seen that innovators and organizations with the most advanced multimodel strategies and tactics often use process architecture as a starting point, not an ending point, in the design of their improvement solutions. However, process architecture can be informed and guided by strategic categorization and tactical composition of models. In theory, you can, at least partially, generate the process architecture from

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[1] In this series of white papers, we use the terms *improvement technologies*, *technologies*, or *models* somewhat interchangeably as shorthand when we are referring in general to the long list of reference models, standards, best practices, regulatory policies, and other types of practice-based improvement technologies that an organization may use simultaneously.

the model composition—if the model interoperability characteristics are understood and the tactical connections (overlaps as well as differentiating features) have been fully characterized. These realities support the notion that the harmonization reasoning framework involves both a process paradigm and an aligned vertical layering of the design and implementation aspects of the harmonization.

In reality, any methods to support the development of a process architecture and its relationship with model strategy and composition are currently "state of the art." In fact, many organizations using process architecture as connoted by our harmonization approach consider it to be part of their competitive advantage and do not often share many details publicly. That said, in this 4th white paper of our series on multimodel process improvement, we share our research on process architecture and provide:

- multiple definitions for what a process architecture is
- highlights of mature and emerging methods that can be leveraged to develop one

Because research for process architecture is still emerging, we have changed the tone of this white paper relative to the others in this series. Our purpose is to raise awareness about process architecture and why it is important and, thereby, to establish a foundation (and a priority) for near-term research.

DEFINING PROCESS ARCHITECTURE

In the engineering of software-intensive systems, we typically consider the product (software and system) architecture. This consideration is not restricted to software, however. We also commonly see it in the construction of buildings (and other "products" of architects and civil engineers). But…do we see architecture applied to the creation of processes?

Yes! We see it in business process development as well as in some of the engineering process models with which we are familiar. Here is a sampling of process architecture definitions:

- CMMI[®]
  Ordering, interfaces, interdependencies, and other relationships among process elements in a standard process [CMMI DEV 1.2]
- Kasser
  Function of process architecting is to design, set up and continuously optimize, the process for the development of the specific system being produced [Kasser 05]
- Business Analysis Body of Knowledge
  Processes needed to conduct business, how those process interact and how they are managed and modified over time.
  - A process architecture should remain fairly intact even as the details of process execution evolve and change. [BA Insight 06]

These definitions are different, yet complementary, and provide a foundation for an examination of process architecture.

METHODS AND TECHNIQUES TO DEVELOP YOUR ARCHITECTURE

Many researchers have considered the question of process architecture, and have posed higher level taxonomies (of similar genre to those we have already put forward), have developed specific methods, or have simply raised the need for this topic to be discussed. Publications that have generated awareness, ideas and approaches related to the subject area include

- Armstrong's work on a systems approach to process infrastructure [Armstrong 05]
- Kasser's work on process architecting as a needed role in organizations [Kasser 05]
- Detailed work by Halvorsen et al. on a series of four comparison methods to use on SPI frameworks, one of these being used to generate a taxonomy of 25 relevant characteristics [Halvorsen 01].

Others who have performed pioneering work in this area include Mutafelija, who addressed the subject of process architecture views and properties [Mutafelija 06], and Bendell, who has conducted work on how to structure business process improvement methods [Bendell 05]. While Osterweil's work does not use the term "process architecture," his examination of macro and micro processes and his development of the Little JIL process language directly relates to this topic. [Osterweil 1] [Osterweil 2] [Avrunin]

We believe developing a process architecture requires taking one step back and considering the needed properties and features. Based on these works and examples of process architectures among innovators who have shared their cases with us, here is a list of features to consider:

- Functional properties, including classes, flow, and attributes
- Inputs and Outputs, including flow and relationships
- Roles and responsibilities, including users and actors
- Information flow
- Overall interrelationships, dependencies, and constraints

The content of these features can be informed by the strategic and tactical model classifications as well as model composition discussed in the 2nd and 3rd white paper of our series. Additionally, there are numerous diagramming and evaluation techniques that may be leveraged from within and outside of the software engineering discipline. The following is a simple list of possibilities that are provided as starting points, based on technical and logical evaluations as well as observation of practices among organizations we have studied. Through future research, we plan to document case studies and develop guidance for when and how to leverage these methods.

Table 1: Process architecture development techniques

Source reference	Techniques that may be leveraged for process architecture development
Design for Six Sigma, Design for Lean Six Sigma, and other robust design techniques	Process mapping and value stream mapping
Software and related engineering technologies	▪ Interoperability principles and practices, including leveraging business process interoperability and approaches to service-oriented architectures. Also, in addition to leveraging design methods, consider adopting a "service orientation" philosophy for process architecture ▪ The validated architecture process of the Evolutionary Process for Integrating COTS-Based Systems (EPIC) [Albert et al. 02] ▪ The Unified Modeling Language, including structure, behavior, and interaction diagrams ▪ The Little-JIL Process Language, a hierarchical process decomposition using procedure invocations and providing for rigorous definitions and automation. [Osterweil 1] [Osterweil 2] [Avrunin] This may provide enable generation, simulation and validation of multimodel based processes. ▪ Software architecture technologies, including ATAM and QAW, can be leveraged to examine the properties of process architectures and the relationship to their ultimate performance.
Architectures and models for business process management	▪ Architecture of Integrated Information Systems (ARIS) applied to business process modeling [Scheer 00; Davis 01] ▪ Riva's process definition technique (using role-activity diagrams) and process architecture technique [BA Insight 06; Ould 05] ▪ Goal-Oriented Business Process Modeling [Bider 05]
Beer's Viable Systems Model	Organizes systems in a way that meets the demands of surviving in the changing environment; subsystems include primary activities, information channels, controls, environmental monitoring, and policy [Beer 85; Beer 94; Espejo and Harnden 89]
Operations Research	Preliminary investigations have indicated that the operations research body of knowledge may be applicable. This needs to be investigated for applicability to software and systems engineering.

RESEARCH DIRECTIONS

Building upon the emerging and existing techniques (

Table 1) and experience reports from the field, we believe that a research need has emerged in this multimodel context that has not benefited from focused attention. It involves the examination of the interoperability and architectural features of different process technologies. In light of the challenges facing organizations striving to succeed in multimodel integration, an advancement of our understanding of these issues has now become essential, and raises several research questions, including:

- What is the definition of "process architecture," in the context of improvement technologies?
    - What is the appropriate level of granularity of functional properties such as classes, flow, attributes; outputs; information flow; relationships; roles & responsibilities; and constraints?
    - Is there an architecture documentation format that effectively and efficiently links model compositions and detailed process descriptions?
    - How do we reconcile different views of architecture from relevant sources such as CMMI, the Business Analysis Body of Knowledge, and multiple, independent researchers such as Kasser, Armstrong, Osterweil, and others?
- How is process architecture derived from (or distinct from) technology classification and composibility?
    - Can effective technology interoperability and composition provide or lead to the process architecture?
    - What level of granularity of technology interoperability and composition is really needed? Are the higher level taxonomies currently available sufficient?
    - How is technology interoperability managed relative to process architecture?
    - Is there a relationship similar to what exists in the controls system technology, where there are communications standards that allow different systems and instrumentation to be assembled into the same system with the components "communicating across a common backplane"?
    - What are the "-ilities" of process that need to be addressed? How do the architectural and interoperability characteristics of the reference models affect or influence the architecture, composition and "-ilities" of process?
- How do situational and system complexity affect how we architect and compose a process?
    - Do they influence prioritization/relevance of characteristics of technology architecture/interoperability and subsequently influence process performance?
    - Do we need the capability for "predictable assembly of process components"? And what constitutes a "process component"? Is it a reusable process definition and procedure, a process capability embedded within tools, a process model or standard embedded within tools, and/or something else?

The objective of such research will be to develop the underlying principles and process characteristics for architecting internal processes, in the context of effectively composed combinations of technologies. An improved understanding of the technologies' interoperability and architectural features will enable practitioners to characterize technical and structural relationships among technologies and to connect this with the creation of a process architecture. Additionally, it will inform researchers' incorporation of interoperability features into their technologies. Therefore, this will improve adoption effectiveness and robustness in the face of dynamically composed processes that are anticipated in increasingly complex product, organizational, and supply chain environments.

SUMMARY

For practitioners, this research may produce outputs, such as the following.

- A preliminary taxonomy of existing and needed interoperability and architectural characteristics of process technologies.

- Identification of reusable technologies from other disciplines for creating architectures, such as operations research, software engineering architecture notation/analysis languages, and SoS engineering.

- An initial collection of plausible scenarios reflecting both the composition of process technologies to inform organizational process definition and the composition of said technologies in environments that are dynamic over time. These include both organizational environments (single and multiple organizations) and technical environments.

- In the context of the above, the recommended features and characteristics of a process architecture, at the appropriate level of granularity, and the corresponding reconciliation of different process architecture definitions.

- Pre-implementation modeling and simulation to accompany the architecture as it is designed and implemented.

- Mechanisms to analyze the behavior of a system with respect to quality attributes, which will enable the following:

  – Prediction of behavior before process systems are deployed
  – Understanding of process behavior after process systems are deployed
  – Design decisions during design and during evolution

Process architecture has been observed as being critical to the success within multimodel process improvement; yet it is currently "state of the art." Technologies from within and outside of software engineering can be leveraged to create a robust architecture that is easily deployed and evolved and is compliant to the models of choice. More work needs to be done to transform process architecture approaches to "state of the practice." The ideas and questions described in this paper provide a foundation for this research.

PROCESS ARCHITECTURE IN PRACTICE

Internal corporate initiatives at companies like Lockheed Martin IS&GS have addressed some of the issues around process architecture and approaches to addressing model integration, primarily within the framework of their own process landscape. Such high-performing organizations are creating, in a "state of the art" manner, their own process architectures. The good practices inherent in these proprietary approaches still need to be codified for wider industry usage, thereby becoming "state of the practice." Consulting companies like ISD in Brazil have developed their own approaches to tackle multimodel process improvement issues at a strategic model composition and process definition level, and have begun to address the interoperability and process architecture problem. [Byrnes 07]

Following are highlights from Lockheed IS&GS's approach to process architecture and an internal standard operating process. This is from their case study which is more completely described in CMMI & Six Sigma: Partners in Process Improvement. [Siviy 07-1]

Lockheed Martin IS&GS's standard operating process, which eventually became known as the Program Process Standard (PPS), began as the Required Development Process (RDP) (Note: The name change resulted from the ultimate desire to eliminate the word development and expand the defined process into different types of programs.) The vision associated with the standard operating process was that it makes it feasible to introduce one overall process to the organization. It also had to reflect the tasks and functions necessary to fulfill organizational project and product commitments. Additionally, it had to reflect the features of three standards of interest to the organization: the SW-CMM, the SE-CMM, and ISO 9000. The long-term vision was that new standards, process methodologies, and process initiatives would be integrated with this single operating process, thus allowing the organization to grow and evolve its capability via new releases of its standard process.

The RDP and PPS both started with an overall workflow diagram of what processes were necessary for the organization. Each process defined was then given a functional owner, a group that had primary responsibility for the process itself. Other functions that also had responsibilities for tasks within that process were defined as support functions. A table was generated to illustrate functional responsibilities, primary or support, for each process. The process was then dissected and tasks within the process enumerated. Once tasks were enumerated, entry and exit criteria as well as inputs and outputs were defined. Once the entry and exit criteria and inputs and outputs were represented by the functional process owners, they were modeled to define relationships and interfaces between processes. Every entry or exit criterion needed a task in another process. Every input had to be an output from some process. This modeling represented not only a simulation of the workflow but it enabled the organization to illustrate and streamline the overall process implementation.

The PPS architecture started with describing the processes that the projects within the IS&GS organization needed to operate. This was coupled with a mapping of the process to the organization's business objectives and goals. The document was designed to be flexible enough to adapt to the requirements of multiple industry standards and models. The organization needed a project-focused document that would be simple enough to be accepted but comprehensive enough to meet all needs. The document met these needs.

Lockheed Martin IS&GS used process-mapping techniques to evolve the initial PPS and develop an architecture for the standard process. Figure 1 represents a high-level view of the overall process map, showing specific processes linked to various organizational functions. In the center are three concentric circles, but the circles are at different levels. The inner circle represents the IS&GS process architecture, the next circle represents the organizational process assets, and the outer circle represents the programs' implementation of the process assets. The outer circle defines the lifecycle of a system of systems, from procurement through transition and operations. Two groups of processes related to the two tiers of the existing version of the PPS: management and control (support tasks) and program implementation (repeated development/engineering processes). The program management and control processes, listed at the bottom of Error! Reference source not found., span all processes within the PPS. The list on the right in Figure 1 represents program implementation and contains all processes—from requirements to operations and maintenance—associated with the development, delivery, and maintenance of an actual system. The list on the left was added to address system-of-systems concerns and the system support activities, which has now become very important in the organization.

After the high-level diagram was developed, the underlying processes were defined by functional process owners and subject matter experts. Program responsibilities for each process were identified. One of the challenges the process designers faced was what level of detail to define. Using the philosophies of "keep it simple" and "the process should reflect how we do business," they created a process template and limited each process description to one page. The template was designed to focus on what the program needed to know: purpose, intent, entry and exit criteria, inputs and outputs, activities and tasks, with the latter written in terms of what to do. Where a SW-CMM KPA matched the process, the KPA goal was used as the primary reference for the process purpose. The KPA practices helped identify the needed process activities.
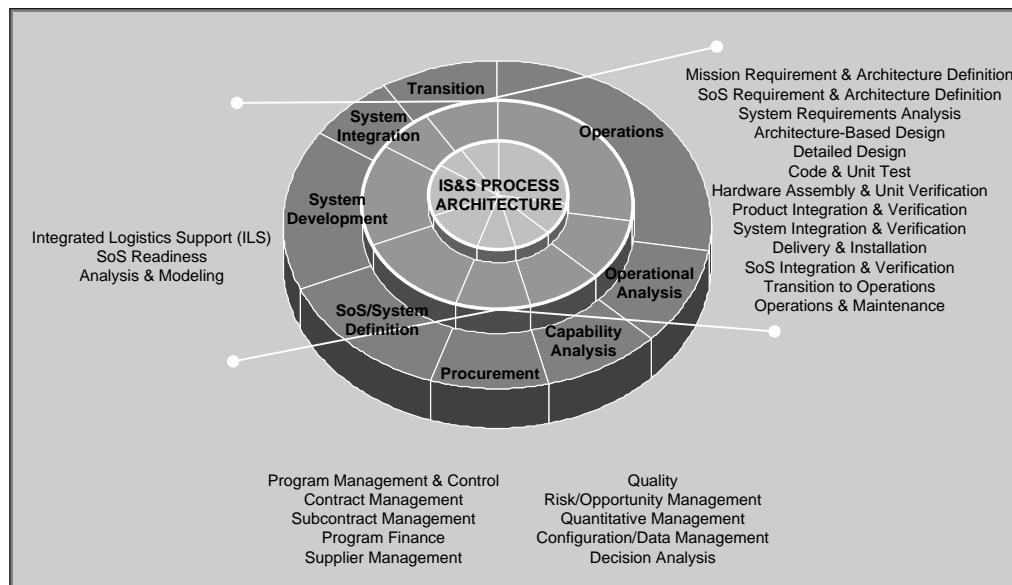

Figure 1: LMCO IS&GS process architecture

A small process group, comprising standards experts, then mapped the process standard to the SW-CMM, the SE-CMM, and ISO 9000. The book containing the workflow diagrams became the minimum mandatory set of processes for all programs. Each process was identified as part of management, engineering, or support/sustainment. Each activity within the process could be mapped to a recommended procedure within the process asset library. The organization did not require the use of these procedures, but if they were used, full compliance to the PPS would be assured. However, the procedures could be tailored and still meet the intent of the process purpose (the required portion of the process). By design, the organization could follow one document, and the reward would be compliance to the SW-CMM, the SE-CMM, and ISO.

The product suite also included a compliance matrix, which each program was required to complete, demonstrating: how the program was compliant (pointers to program procedures), which processes were being tailored, and which of those processes needed waivers. A template was then created for a typical program plan based on the standard process, with elaborations on procedures that programs could adopt in order to assure compliance. A program plan was required on all programs.

After the foundational elements of the process improvement program were solidly in place and in a routine two-year review cycle, and as the organization evolved via organic growth and organizational acquisitions, the PPS was expanded to include tailoring guidelines based on program type; the list of program types was updated as well. For instance, program types that did not include full-scale software development were explicitly included, such as operations and maintenance, support, and special studies. …. Templates for the PPS Compliance Matrix and Program Plan were defined for each program type.

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The following are the references used in this white paper. Additional reading materials are listed in the "References" and the "Additional Resources" appendices of *CMMI & Six Sigma: Partners in Process Improvement*. This listing includes both model-specific references (for CMMI & Six Sigma, as well as other combinations) and multimodel references.

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